Energy in Agriculture: Energy Resource Series for Youth and Adult Energy Programs: 12. Alcohol

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AEES-32

ENERGY IN AGRICULTURE

Energy Resource Series for Youth and Adult Energy Programs

12. Alcohol

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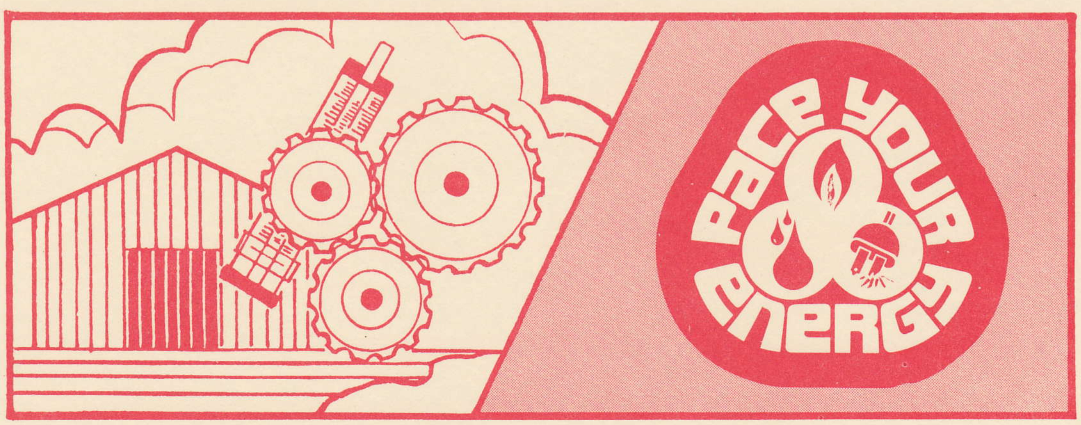

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Preface

The vast supply of relatively cheap petroleum fuel we have had is what has made our present standard of living possible. In fact, petroleum is the basis of about everything we enjoy today. To maintain this standard, new sources of energy must be made available. Alcohol is one such energy source.

We read and hear a lot about the possibility of using alcohol as a motor fuel. For use in automobiles, alcohol is mixed in small quantities with gasoline. Used full strength, alcohol also may have possibilities as fuel for certain critical segments of our society, such as agriculture.

The production of alcohol is a very sensitive process. The weather is a critical factor in crop production, and it also is essential that the microorganisms needed for alcohol production be present. Because of the wide publicity given this fuel, this publication explains alcohol production in some detail.

This is the last publication in a 12-part energy resource series designed for the adult and student with a serious interest in the energy situation. Each publication examines a different energy source and considers the advantages and disadvantages associated with its use.

When necessary, diagrams and/or tables are used to clarify or elaborate upon information found in the text. Questions with answers are included at the end of each publication so that you can test what you have learned.

The author wishes to thank Wilbur Frye, Joseph Taraba, Larry W. Turner and Linda Bach, Department of Agricultural Engineering, University of Kentucky, for reviewing the text.

The Energy Resource Series for Youth and Adult Energy Programs includes the following publications:

AEES-21 Energy Overview
AEES-22 Definitions
AEES-23 Oil and Gas
AEES-24 Coal
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Introduction

Today we often hear discussed the potential energy content and ability of alcohol to lessen our dependence on gasoline as a motor fuel. The alcohol in question is ethyl alcohol, a colorless, volatile, flammable liquid that is derived from growing plants, or the parts of growing plants, that are relatively high in carbohydrate content.

Because ethyl alcohol is derived from growing plants it is an annual, renewable energy source. This contrasts to our finite fossil fuels; they are renewable, but aeons of time are required. Table 1 lists some plants, fruits and grains that have relatively high carbohydrate content and could be processed to form alcohol. The list does not contain all possible alcohol sources, nor should it be implied that each item listed will provide an efficient source of alcohol. In this publication, the steps required for producing alcohol are outlined. You will then more easily understand which plants, fruits and grains could be utilized most profitably to make alcohol.

Table 1.—Carbohydrate Content of Common Table Foods.

Food	Carbohydrate Content (%)
Sugar (table)	100
Rice	90
Prunes	73
Molasses (cane)	69
Lima Beans	66
White Bread	53
Whole-wheat Bread	50
Banana	22
Corn (kernels)	19
Potato	18
Cherry	17
Grapefruit	14
Apple	14
Pear	14
Orange	12

Origin of Energy

All living plants get their energy from the sun. This process is called photosynthesis, which means "put together with light." This is literally what happens.

To help you understand photosynthesis, let's take a brief look at the action of an electric eye. Most people are aware of the usefulness of the electric eye. It can open doors, count objects moving on an assembly line, make movies talk and act as a burglar alarm. All this comes under the heading of "photoelectric effect."

If the surface of a piece of material is coated with a layer of cesium (Cs), electrons will be emitted from this surface when it is exposed to sunlight or other strong light. Cesium is number 55 in the table of elements. Each cesium atom has 55 electrons orbiting around it in six different levels. The outer level contains only one electron. This electron is at a relatively great distance from the positively charged center. Because of this great distance the electron can be knocked out of its orbit if struck by a sufficiently strong force. Such action is called ionization. The cesium, after losing an electron, is called an ion. Cesium is the easiest of all the elements to ionize. A photon of light vibrating at 4 1/2 trillion cycles per second (visible light range) striking the outer electron of cesium has sufficient energy to remove it from orbit.

The billions upon billions of electrons that can be forced from the surface of cesium are made to move through space to a highly positively charged plate. These moving electrons constitute an electric current that is the working basis of the electric eye. This electric current, even though very small, can be used to control many devices. For instance, to open doors a beam of light is positioned across the pathway leading to the door (Figure 1). The beam of light shines into an electric eye (cesium-coated material) causing the small amount of electric current to flow, which in turn is used as a signal to control more powerful electric door locks. If a person passes through the beam of light, the flow of electrons from the cesium in the electric eye ceases,

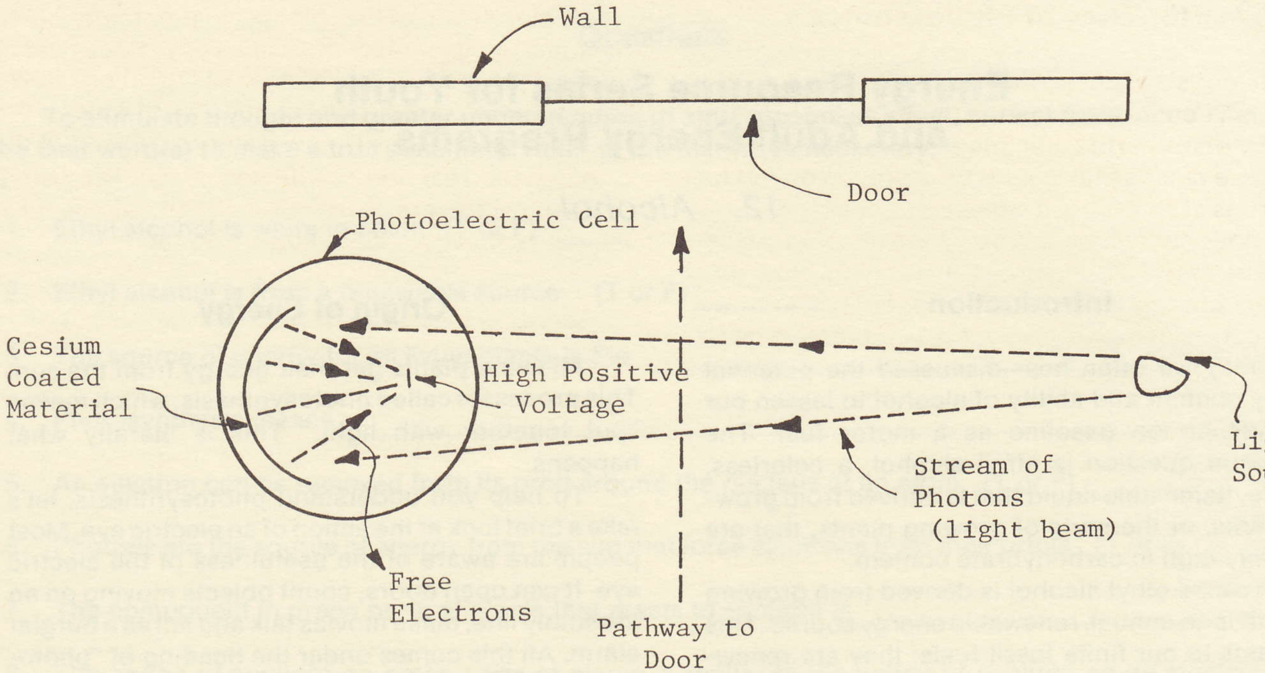


Fig. 1.—This top view of a door and photoelectric cell with light source illustrates the action of the electric eye. A person approaching the door along the pathway breaks the light beam and in turn stops the flow of electrons within the photoelectric cell. When this internal electric current stops, a signal is sent to electric switches that open the door.

triggering the release of the door locks. The door then swings open by electric motors or springs, allowing the person to pass. Many times a second electric eye is used to close and lock the door after the person passes through.

Chlorophyll: The Key

In all green-colored parts of plants, especially the leaf, chlorophyll molecules exist. Electrons orbit these large molecules. A photon of red, blue or violet light traveling through space at the speed of light (186,000 miles per second) and vibrating at 4.46×10^{14} or 6.75×10^{14} cycles per second (cps) may strike one of these outer electrons (see AEES-25 Solar and AEES-29 Wood for more detail). The force of this collision transfers all of the energy, that is, quantum, of the photon to the electron and boosts the electron to a much higher energy level. The photon ceases to exist because all of the energy was transferred. The electron is captured by other molecules and starts the first of several steps of chemical changes to take place, leading eventually to simple sugar compounds (carbohydrates).

By this time, the electron has lost the extra quantum given by the photon, and it returns to the chlorophyll molecule ready to be hit again by another photon. In all this action the electron and chlorophyll can each be considered a catalyst. They each help the chemical reactions to take place, but they do not stay in the final compounds.

The products of these actions are carbohydrate molecules. They are of higher energy content than the original raw product molecules by the amount given by the high energy electron. Figure 2 illustrates the effect of light on chlorophyll.

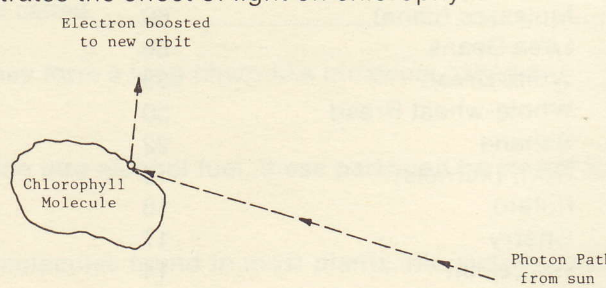


Fig. 2.—Effect of light on chlorophyll. A photon of sufficient energy hits an outer electron of a chlorophyll molecule and boosts it to a higher energy level. Here the high energy electron is captured by other molecules, and its energy is used to start making energy rich molecules called carbohydrates.

Efficiency of Photosynthesis

Scientists estimate that less than one-tenth of 1 percent (1 out of 1,000) of the photons reaching the surface of the earth enter into photosynthesis. Here are some reasons for this. Many photons do not hit electrons of chlorophyll molecules because chlorophyll does not completely cover the earth's surface. Photons might hit electrons a glancing blow and bounce off, imparting insufficient energy to move the electron to higher levels. Also, photons must be in a rather narrow or specific band of energy frequencies to move the electrons, that is red, blue or violet. All the vast numbers of other photons from the sun won't work. Their energy content or frequency is not correct for dislodging the electron from its lowest orbit.

An interesting point established by research is that plants use from 15 to 50 percent of the photosynthetic energy for their own living energy or metabolism. The energy that is left over is stored as potential chemical energy in the form of carbohydrate molecules in the plants. It is these molecules that are of interest for production of alcohol.

Another important point is that plant scientists estimate that only 10 percent of photosynthesis takes place in plants on land. The other 90 percent takes place in green algae in the oceans. Nevertheless, scientists estimate that the green plants on land manufacture 400 billion tons of carbohydrate material each year.

Photosynthesis at Work

In the leaves and other green parts of plants the raw materials, carbon dioxide (CO_2) and water (H_2O), are broken up and reassembled to start the steps leading to more complicated, higher energy carbohydrate molecules. The carbon dioxide comes from the atmosphere, and the water comes from the soil.

In empirical type formula, this action is shown in the following chemical equation:

$$CO_2 + 2H_2O \xrightarrow[\text{Sunlight Energy}]{\text{Chlorophyll}} O_2 + CH_2O + H_2O$$

Remember that the CO_2 on the left comes from the atmosphere, and the two water molecules come from the soil. The oxygen molecule (O_2) on the right is released to the atmosphere, the single water molecule is released as vapor to the atmosphere or can condense with other molecules and drip to the ground. The CH_2O molecule is retained in the plant.

It may seem, at first glance, that nothing much happens in this reaction, especially since water appears on both sides. Closer observation, however, shows that only half the quantity of water is on the right. In fact, this is new water and does not go through the reaction unaffected. Scientists using radioactive tracers have found that the atoms take the paths shown in the following equation.

$$CO_2 \quad + \quad 2\,H_2O \longrightarrow O_2 \quad + \quad CH_2O \quad + \quad H_2O$$

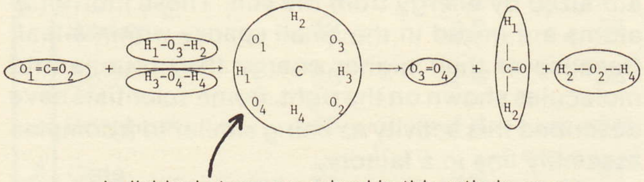
It can be seen from this empirical formula that the oxygen in the new water came from the carbon dioxide in the atmosphere. In fact, all the molecules of the raw material on the left are broken apart or atomized by energy from the sun. These individual atoms are mixed in the small spaces within a leaf. Because of their higher energy they reunite into molecules shown on the right. Some scientists have described this activity as being similar to a complex assembly line in a factory.

The carbon dioxide and the water molecules are two molecules that represent low energy content. The bonds holding carbon and oxygen together, as well as the bonds holding hydrogen and oxygen together, are stronger than those holding the compounds on the right side together. Energy must be expended to break them apart. This comes from the sun. This situation is somewhat similar to a large boulder lying at the foot of a hill. It is in its lowest energy position. Its energy has been spent by rolling downhill. If energy is expended and the boulder is lifted and set on the top of the hill, it would be in a high energy position. Just a little bit of energy is needed to move the boulder to the edge of the hill. Then the boulder seeks out the low energy position by rolling down the hill.

Identifying a Carbohydrate Molecule

Carbohydrate molecules represent energy rich atomic combinations, similar to the boulder on top of the hill. These molecules can be recognized by the fact they contain carbon (C), hydrogen (H) and oxygen (O) with the hydrogen and oxygen always in the ratio of water. That's what the word carbohydrate means—carbon united with water. Historians tell us that early chemists suspected that water molecules were actually attached to carbon molecules in the carbohydrate molecule. They began using the term "water-carbon" which later became hydrocarbon. However, a very important fact must be pointed out here. The hydrogen and oxygen are not actually water in these molecules as will be seen later when diagrams of this molecule are shown. Empirical formulas, such as CH_2O or $C_2H_{12}O_6$, simply indicate the ratio of atoms in a molecule but not the actual arrangement. There are several ways these atoms can be connected in a stable molecule and some of these will be shown later in actual diagrams.

The way the raw material is broken apart and new, higher energy molecules formed may be more easily understood by studying Figure 3.



Individual atoms are mixed in this ratio in open spaces or cavities of a leaf.

Fig. 3.—Chemical action caused by energy in sunlight. Each atom has been numbered or tagged with a subscript allowing each to be followed through the reaction. Each letter represents an individual atom. A circled group of atoms represents a molecule.

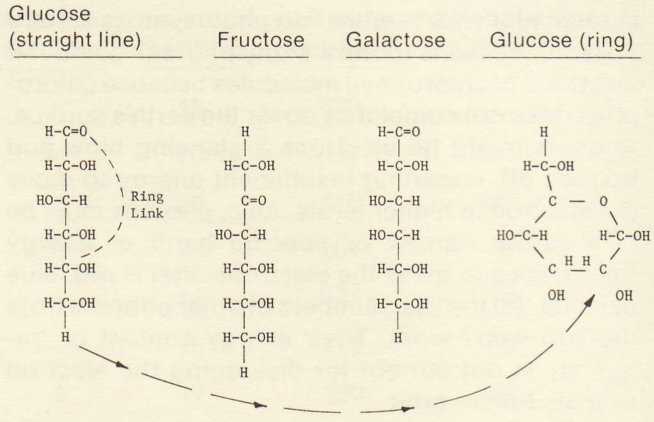
Now, note that several of the molecules can be put together by the plant to form more complex carbohydrates as the following formula indicates.

$$6CO_2 + 12H_2O \longrightarrow 6O_2 + C_6H_{12}O_6 + 6H_2O$$

All the molecules are in the same ratio as the first formula. The carbohydrate on the right is a simple sugar. These molecules are the building blocks of the plants.

Researchers have found that the carbohydrate molecules, put together by plants, can be divided into classes. The first are shown in Figure 4 and are single molecules called simple sugars or monosaccharides. The three most important arrangements, so far as common products from which alcohol can be made, are listed in this figure as glucose, fructose and galactose.

Basic Carbohydrate Molecules
$C_6H_{12}O_6$



All three can form rings similar to this.

Fig. 4.—Monosaccharides or simple sugar molecules are made up of single molecules. These are the simplest of all carbohydrate molecules. All other carbohydrates are combinations of these three basic molecules. These molecules can easily be turned into alcohol by fermentation. These also are called isomers because each has the same number of each kind of atom but a slightly different structure.

Notice that in each arrangement the number of carbon atoms is the same. This is also true of the hydrogen as well as for the oxygen atoms. This is why the empirical formula does not give the complete story in complex molecules. Diagrams and sometimes three-dimensional models are necessary to fully illustrate them.

It is also quite common that the long, chain-like molecules become connected in circular or ring-like fashion. This is shown by the glucose molecule as a straight line molecule on the left and in ring configuration on the right. Each molecule still has the same number of each kind of atom, whether in a line or ring arrangement so the empirical formula remains the same. The ring arrangement is important because it is in this form that it can be joined to other similar molecules to form still more complex molecules.

Refer now to Figure 5. A second class of carbohydrate molecule is shown with three of the most important groups listed. These arrangements always contain two molecules and are called complex sugars or disaccharides. Notice that to make maltose, two glucose molecules are combined. To make sucrose one molecule of glucose and one of fructose come together. Lactose is formed when one molecule each of glucose and galactose are attached. Glucose appears most often in all these combinations. It is therefore the most important sugar.

Complex Carbohydrate Molecules
$C_{12}H_{22}O_{11}$

Maltose (two glucose)	Sucrose	Lactose
	glucose ring and fructose ring	glucose ring and galactose ring

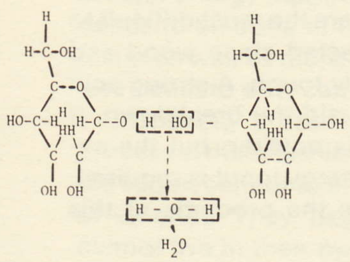


Fig. 5.—Complex carbohydrate molecules are made from the three basic single molecule sugars. Only the maltose molecular buildup is illustrated. Sucrose and lactose buildup are similar.

The actual attachment between two molecules is made at the ends of the ring where there is an hydroxyl group (OH). Under proper conditions when the two molecules get close together the two hydrogen atoms and one oxygen hook up because of great attraction to form water (H_2O), and the remaining oxygen atom connects the two molecules together into one large molecule. Count the individual atoms in this large molecule and notice the 12 carbon, 22 hydrogen and 11 oxygen. Notice the hydrogen to oxygen ratio remains 2 to 1. With the carbon and the H_2O ratio it is still a carbohydrate molecule. The empirical formula for this action is:

$$2\,C_6H_{12}O_6 \longrightarrow C_{12}H_{22}O_{11} + H_2O$$

Thus, two glucose molecules have been joined by removal of water. This is known as a dehydration process.

It is very important to remember this action since in the processing of raw materials into alcohol the reverse of this process or hydrolysis (adding water) is used to reduce complex carbohydrate molecules, found in plants, to simple sugars. This is necessary because yeast cells needed for fermentation can only ingest the simple sugar molecules.

The third class of carbohydrates is very complex. One molecule may consist of many simple sugar molecules in a repeating structure somewhat similar to a string of identical rail cars. These complex molecules are called polysaccharides.

The most important types of polysaccharide, so far as alcohol production is concerned, are starch and cellulose. These are too complicated to illustrate in this publication as was done for monosaccharides in Figure 4 and disaccharides in Figure 5. Starch and cellulose are hooked together in a similar way to the maltose molecule shown in Figure 5 except that the structure is repeated many times. Diagrams of these two types of carbohydrates can be found in advanced texts on plant sciences.

Most people have had experience with cellulose. These are the molecules that give strength to the stalks and stems of plants. Corn and potatoes are examples of vegetables that contain large quantities of starch.

Carbohydrates as Stored Energy

Now, if good growing conditions prevail, we have fully grown mature plants with carbohydrates stored as starch or cellulose. All of these can be converted to alcohol; the more complex the compound the more difficult and costly it is to process. Therefore, the parts of plants containing the simpler or less complex molecules are sought for use in producing alcohol. Less complex sugar molecules are found in the roots of sugar beets, carrots, potatoes or artichokes and in the kernels of wheat, corn or rice. The stem or stalk of sugar cane is utilized in alcohol production. Table 2 lists common classes of carbohydrates and their uses.

Table 2.—Classes of Carbohydrates.

Carbohydrate	Description
Monosaccharides	
Glucose	The simplest molecular structure of all sugars. Needs no digestion. Can be injected directly into the blood for immediate nourishment. Human digestion breaks down all carbohydrates to glucose.
Fructose	Abundant in fruit juices and in honey.
Galactose	Molecules join together to make lactose.
Disaccharides	
Maltose	Produced from sprouted grain; as 'malt' it converts starch molecules to simple sugars for fermentation.
Sucrose	Table sugar. Directly from sugar cane or beets.
Lactose	Milk sugar.
Polysaccharides	
Glycogen	Carbohydrate storage in animals.
Starch	Carbohydrate storage in plants.
Cellulose	Chief (strength) structural component of cell walls of plants; indigestible for humans.

The parts of mature plants to be processed into alcohol can be stored under proper conditions for many months or years, until ready for processing. The objective in the processing procedure is to get all complex sugar molecules broken down to the simple sugar molecules so that fermentation can take place.

Conversion of Carbohydrates to Alcohol

The production of ethyl alcohol may proceed as shown in Figure 6. Plants that store carbohydrate in the form of sugars, starch or cellulose are listed in three columns. These are known as bio-material and are renewable forms of energy. Methyl alcohol can be made from fossil materials, such as coal, but these are finite fuels that take aeons of time to form.

Alcohol Production

	Sugars	Starch	Cellulose
Phase I	sugar cane sugar beets molasses fruits	grains sweet potato white potato carrots artichoke	wood & by-products municipal waste paper
Phase II	crushers used to extract the juice containing sugar sugar, $C_6H_{12}O_6$ ↓	ground; then water and heat added to form gelatin or mash starch and enzyme (malt) added to hydrolyze sugar sugar, $C_6H_{12}O_6$ ↓	strong acid or base added to chipped or ground material to form sugar sugar, $C_6H_{12}O_6$ ↓
Phase III	Yeast ferments sugar to alcohol $C_6H_{12}O_6 \longrightarrow 2\,C_2H_5OH + 2\,CO_2$		

Fig. 6.—The raw material or plants harvested from the field are shown at phase I. Next they receive specific treatments to reduce or hydrolyze the complex carbohydrate molecules to simple sugar (phase II). In phase III the sugar is fermented to alcohol and carbon dioxide.

The materials in the first column of Figure 6 are high in sugar content, usually of the disaccharide form. Some fruits, such as grapes, contain large quantities of the simple sugars. The raw materials are sent through some form of mechanical crusher. This breaks the skin open and exposes the sugar molecules for quick fermentation.

The materials in the starch column require more preparation before fermentation. These must be mechanically ground to expose the carbohydrate molecules. Water and heat are added to form a gelatin-like substance of high starch content. When the water content and temperature are right, a chemical (enzyme) called malt is added to hydrolyze the large molecules to simple sugars. You should recall the inverse process of dehydration in Figure 5 when molecules of single sugars were hooked together in growing plants.

The cellulose materials are the most difficult to process. This is to be expected since wood and stems of plants are physically tough. A strong acid or base (alkali) is added to aid the breakdown. If heat is added the process is quicker, but the expense is greater and more energy input is required. Simple sugar molecules are the products of this breakdown.

Role of Yeast in the Fermentation Process

After simple sugars are formed from the raw material, living organisms in the form of yeast are added. Yeast is made up of microscopic plants that are closely related to toadstools, mushrooms and molds. They may also be called "fungi." These organisms live as parasites on the sugar and decompose or digest it directly into alcohol and carbon dioxide. The empirical formula for this action is as follows:

$$C_6H_{12}O_6 \longrightarrow 2\,C_2H_5\,OH + 2CO_2$$

Some energy is taken from the carbohydrates in performing this digestion. This energy is radiated away as low grade heat and in producing carbon dioxide. In other words, it takes some energy for the organisms to live. This is one reason why the present alcohol manufacturing system is inefficient.

The fermentation process usually takes place in large vats. The CO_2 bubbles to the top. It can be vented to the atmosphere or collected and sold if there is a market for it, such as fire extinguishers or dry ice. CO_2 is a low energy molecule. Because CO_2 will not burn, it can be used to suffocate fires. Also, because it is in a low energy state it can be used as a heat sink, that is, something cold that heat will flow into.

The solids that cannot be completely digested by the yeast cells settle to the bottom. These can be used as animal feed as they are high in protein.

Some cost may be involved in drying and handling depending on the total system. Between the settled solids and the top is a mixture of alcohol, water and undigested sugar material. Occasional removal and distillation will remove most of the alcohol from this mixture. This is called a batch system. In some systems this can be a continuous process.

Water and alcohol mix easily and some water may be carried over in the distillation process. Thus, two or more distillation steps are usually necessary so that very little if any water remains in the final alcohol produced. These distillation steps represent a major energy input, in the form of heat. Much work needs to be done in this area to make the process faster as well as more energy efficient and possibly less delicate so it can be adopted for on-farm use.

One big problem in the alcohol production process is that the microorganisms (yeast), living on the sugar, cannot tolerate a very high concentration of alcohol. They begin to die off because they cannot live in their own pollution. It is bothersome and costly, but the alcohol concentration must be lowered by frequently removing the alcohol from the vat by distillation. This requires high energy input and new yeast must be added. Research scientists are now attempting to develop new strains of yeast cells that will tolerate higher alcohol conditions. Systems using energy other than the fossil fuels to provide heat for distillation are being developed. Still other scientists are working on ways of removing the alcohol other than distillation.

Ethyl Alcohol: The Final Product

The product of all the steps from the growing plant to final distillation is ethyl alcohol, C_2H_5OH. This is a colorless, volatile and flammable liquid. It can be used now as a fuel in ways similar to gasoline. It can be stored for long periods of time and yet be ready for use at a moment's notice, making it as convenient as gasoline.

The way alcohol is used to produce heat energy is illustrated in Figure 7. The empirical formula

$$C_2H_5OH + 3O_2 \longrightarrow 2CO_2 + 3\,H_2O$$

is shown at the top of the figure. Note that the bonds between the atoms of the energy rich alcohol molecule are indicated as being weak. It is as if they are straining to break apart, somewhat similar to a boulder perched on a hill being tugged at by gravity.

Combustion of Alcohol

The liquid alcohol must be vaporized in preparation for burning or oxidation, that is uniting with oxygen. In an engine, this takes place in the carburetor. Some slight modification of the carburetor may be necessary, especially if alcohol is not mixed with gasoline. Heat must be added to the incoming fuel because alcohol does not vaporize as easily as gasoline. A very small portion (just a few drops) of the liquid is vaporized and mixed with exactly the number of molecules of oxygen indicated as necessary in the empirical formula. This is shown in the second step of Figure 7. Note the single large alcohol molecule surrounded by the three oxygen molecules. This is the ratio demanded by the empirical formula. Surrounding these, just a small fraction of a millimeter away, will be more molecules in this same ratio. This represents the correct gas or vapor mixture of millions of molecules that could fill a volume, such as the inside of the cylinder of an engine.

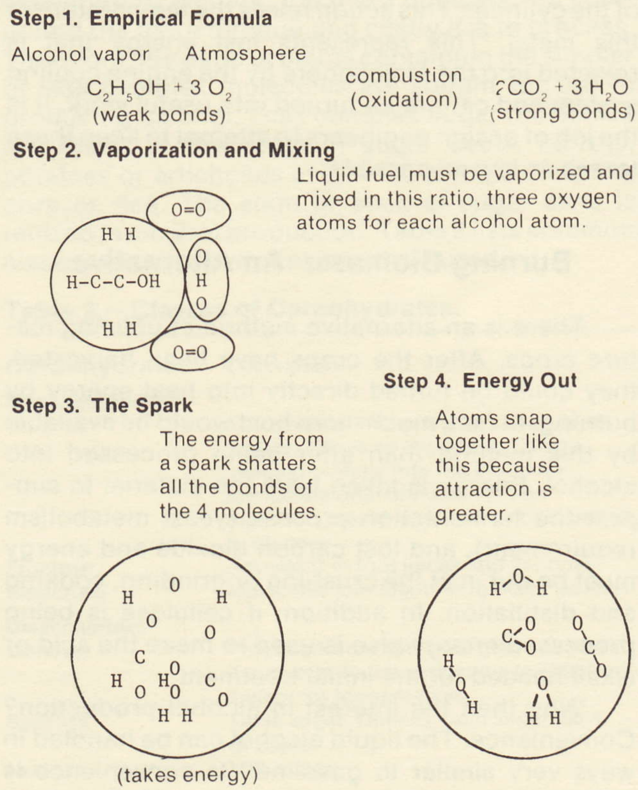


Fig. 7.—Burning alcohol for energy. In step 4, when the atoms snap together, the resulting collision causes the new molecules to vibrate violently, thus giving off energy.

In the third step of Figure 7, a spark occurs at some point within the gas mixture. The energy of this spark breaks all the bonds of the alcohol and oxygen molecules in a very small volume surrounding the spark. These freed atoms snap together as shown in step 4 because they have a greater attraction (like the large boulder rolling down the hill) for each other. When these atoms collide the resulting collisions cause violent vibrations that give off energy to adjacent molecules (this is the flame front), shattering their bonds. A repeated chain reaction progresses through the gas mixture until all atoms have attached in their lower energy form shown on the right of the empirical formula.

The violent vibrations of all the atoms colliding as they snap together in their low energy state cause the temperature and pressure to rise within the engine cylinder. This force pushes against the piston causing it to move so that mechanical motion is possible. This mechanical motion can be harnessed to do useful work.

A large portion of the vibratory motion of the atoms within the gas beat against the sides and top of the cylinder. This action raises the temperature of this metal. This represents lost energy that is rejected into the atmosphere by the engine cooling system and cannot be turned into useful work. It is the job of design engineers to attempt to keep these losses as low as possible.

Burning Biomass: An Alternative

There is an alternative method of utilizing mature crops. After the crops have been harvested, they could be turned directly into heat energy by burning. In fact, much more heat would be available by this method than after being processed into alcohol. Energy is taken from the material to support the fermentation process (yeast metabolism requirement), and lost carbon dioxide and energy must be put in at the crushing or grinding, cooking and distillation. In addition, if cellulose is being processed energy also is used to make the acid or alkali needed for the initial treatment.

Why then the interest in alcohol production? Convenience. The liquid alcohol can be handled in ways very similar to gasoline. Its convenience is well-known, especially as a fuel for a multitude of various mobile vehicles. There are many cases, however, where the bulky bio-materials could be burned with very little preprocessing. One example is the burning of corn stalks and cobs to furnish heat for drying grain rather than using fuel oil or propane. This same material can be used to heat large animal structures or plant growing structures like greenhouses. Some design work is being done on central power plants that could be fueled by biomass materials.

In all these cases the burner or furnace would remain stationary and the large masses of biomaterial could be harvested and packaged, like large round bales, from farm land surrounding the burner site and transported to it. Here the material would be stored so it could be moved to the burner as needed. The contrast in convenience between the raw bio-material and the liquid alcohol where mobility is essential is obvious.

The Complete Renewable Cycle

With the burning of ethyl alcohol and the production of carbon dioxide and water, the cycle of renewable alcohol energy is complete. Green plants with energy from the sun can take these products and start them on their way again to becoming energy-enriched carbohydrate molecules.

Figure 8 is an illustration of this entire cycle. The cycle can start at any point, but it is most logical to start at planting time. Seeds of the desired plants are sown in prepared ground at the proper time of the year. The seeds sprout and grow to mature plants; they are then harvested. Enough seeds from the mature plants must be saved to assure a new crop. The planting and growing usually take just a few weeks time. At harvest the parts of the plants to be used for alcohol (called biomass) may be stored for various lengths of time depending on when the alcohol fuel is needed. It could be just a few days or several years.

When alcohol for fuel is needed, the biomass material starts through the processing plant. The processing time is usually four to five days. The product, alcohol, can be stored for any length of time and used in desired quantities. The burning of the alcohol for heat energy yields products that can be used by new plants, and thus the cycle is completed.

Table 3 lists some plants that could be used to produce alcohol and compares each in several ways. Possibly the most important comparison is the column giving yield of alcohol in gallons per acre (Yield, Gal/Acre).

Other factors must be considered, such as harvesting. The feasibility of growing the plant in certain localities or how much labor is involved in

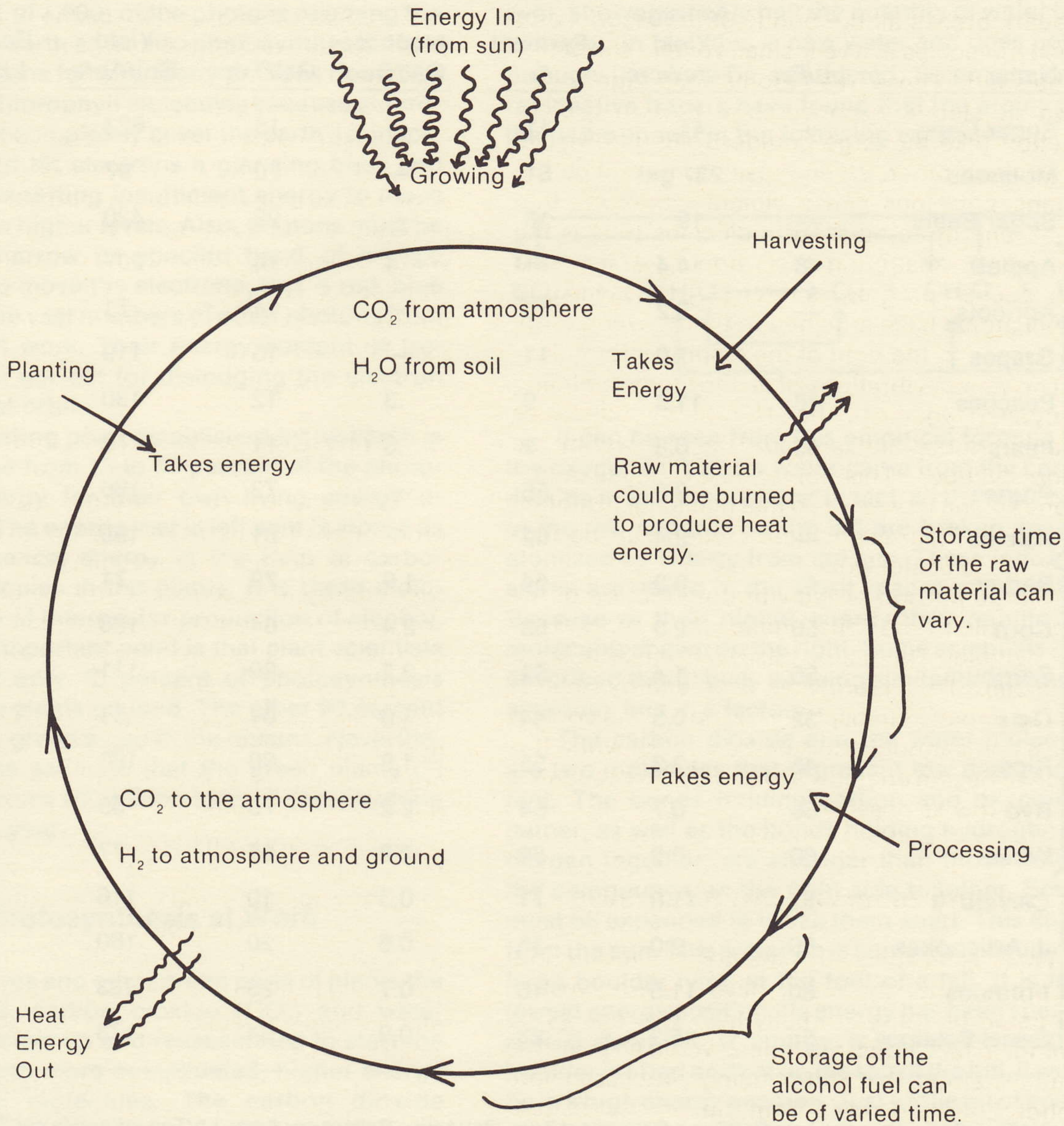


Fig. 8.—The raw material cycle of alcohol. Energy from the sun is stored for awhile as potential chemical energy in the material. When alcohol is burned the energy starts on its way again, never to return.

planting or harvesting must be taken into account. Another factor might be the residual, given in the last column of Table 3 or what is left after harvesting the parts to be processed to alcohol. This residual material can be used for heat in some steps of the processing procedure, such as distillation.

Table 3.—Alcohol Yielding Crops.

		Name	Lb/Bu	Average Yield Ton/Acre	Ferment %	Alcohol Gal/Bu	Gal/Ton	Yield Gal/Acre	Residual Lb/Ton
sugars		Sugar Cane	—	41	11	—	15	623	—
sugars		Molasses	—	237 gal	51	—	70	97	—
sugars		Sugar Beets	—	19	16	—	22	420	100
sugars	fruits	Apples	48	14.4	11	.4	14	207	40
sugars	fruits	Apricots	—	5.2	10	—	14	71	46
sugars	fruits	Grapes	—	7.9	11	—	15	119	76
sugars	fruits	Peaches	48	11.3	9	.3	12	130	34
sugars	fruits	Pears	50	6.8	9	.3	11	78	58
sugars	fruits	Prunes	—	2.3	55	—	72	166	152
sugars	fruits	Raisins	—	2.4	62	—	81	195	166
starches	grains	Barley	48	0.9	54	1.9	79	71	646
starches	grains	Corn	56	2.0	58	2.4	84	168	446
starches	grains	Sorghum	56	1.4	54	2.2	80	111	488
starches	grains	Oats	32	0.8	44	1.0	64	51	846
starches	grains	Rice	45	2.3	55	1.8	80	183	520
starches	grains	Rye	56	0.7	54	2.2	79	55	542
starches	grains	Wheat	60	0.9	59	2.6	85	77	538
starches	roots	Carrots	55	11.8	71	0.3	10	116	76
starches	roots	J. Artichokes	60	9.0	15	0.6	20	180	104
starches	roots	Potatoes	60	11.5	16	0.7	23	263	76
starches	roots	Sweet Potatoes	55	5.2	23	0.9	34	178	92

Key: Gal/Bu = Gallons per Bushel; Gal/Ton = Gallons per Ton; Gal/Acre = Gallons per Acre; Lb/Ton = Pounds per Ton.

Comparison of Alcohol and Gasoline as Fuels

A comparison of alcohol with gasoline is now in order. The general public is familiar with the term gasohol. This is a name given to the mixture of gasoline and alcohol in the ratio of 9 to 1 for use in automobiles.

Users of this mixture generally agree that they get better performance than with straight 100 percent gasoline. Their comments cover all phases of driving, including miles per gallon. To date, there have been no published reports of detailed research on the actual performance of these mixtures.

There have been a few articles on the use of 100 percent alcohol as a motor fuel in foreign countries, namely Brazil. This country apparently is putting forth a major effort to have all vehicles operate on alcohol. A complete nationwide system is being designed to satisfy that need.

The segment of society in the United States that possibly could look at the use of 100 percent alcohol is off-road engines in agriculture. These would be the tractor and other engine driven equipment used on the farms for crop production. A sufficient portion of our production land could be used for raising crops destined for alcohol. Associated processing facilities also would be needed. The remaining land would be for food production. The production agriculture industry would be energy self-sufficient. This situation is similar to the time when production agriculture was dependent on horses. The farmer, during those times, always had to plan on using a portion of his land to produce food for the horses. If 100 percent alcohol were to be used in farm tractors today its use would be more efficient than agricultural production with horses because the tractor uses energy only while working, while the horse used it all the time, whether working or not.

Table 4 compares some of the aspects of gasoline and alcohol. First of all, it is noted that to do a certain job requiring 100 gallons of gasoline about 160 gallons of alcohol would be required. This shows that a gallon of alcohol does not contain as much energy as a gallon of gasoline. In fact, it takes about 60 percent more gallons of alcohol to do a job than if only gasoline were used.

Table 4.—A Comparison of Gasoline and Alcohol.

Characteristic	Gasoline	Alcohol
Octane rating	95	99
Btu per pound	20,000	12,000
Btu per gallon	124,000	95,000

The same fact is true of other fuels as well. For example, to do a given job, it takes about 20 percent more gallons of propane than gasoline. However, to do this same job with diesel would require about 8 percent less fuel as compared to gasoline. If natural gas were liquified it would take almost double the number of gallons to do the same job as with gasoline.

These facts are true because of the nature of the molecules making up each fuel. The main difference between propane, C_3H_8, or gasoline, C_6H_{14}, and alcohol, C_2H_5OH, is that alcohol already has an oxygen atom attached. This lessens the amount of oxygen from the atmosphere that can unite with the carbon and hydrogen during combustion. Some research is now taking place attempting to find efficient ways to remove this oxygen from alcohol and produce gasoline. There are no published results of large scale successes.

Due to the fact that there is less energy in each gallon of alcohol, a vehicle will have to carry about 60 percent more fuel. Storage facilities and bulk hauling will be larger. In most cases these disadvantages will be of little concern. However, all facilities will have to make certain that no water is allowed to enter the alcohol. These mix readily and are costly to separate. With gasoline, the water stays separate and goes to the bottom.

Corrosion resistant materials must be used when concentrations higher than 30 percent alcohol are used. Also, the vehicles utilizing these high concentrations will need to be altered slightly to keep performance and efficiency as high as possible. For the 10 to 20 percent mix, no alteration is needed.

At the present time the total system of alcohol production is rather sensitive or critical in that living substances, such as field plants and microorganisms, are involved. High quality husbandry and constant watchfulness is necessary. By utilizing the crop's residue for input energy in certain phases, more energy can be obtained from the crop than is put in. Research might provide some breakthroughs to make processing more efficient.

The big plus factor, however, is that production of alcohol for fuel is a present possibility and certain critical segments of our society could become energy independent by utilizing it.

Questions

To stimulate thought and greater understanding of ethyl alcohol as a fuel, answer these questions with the best word(s) to make a true statement. Refer to the text when necessary.

1. Ethyl alcohol is white in color. (T or F) ______
2. Ethyl alcohol is from a renewable source. (T or F) ________
3. The source of energy for all living plants is the ____________________.
4. Photosynthesis means ____.
5. An electron can be removed from its orbit around the nucleus of an atom. (T or F) ________
6. Photons are the source of energy from the sun that force electrons from their orbits. (T or F) ________
7. The component in green parts of plants that reacts to sunlight is ____________________.
8. The action of sunlight on green parts of plants is similar to the action of sunlight on an electric eye. (T or F) ________
9. Much more photosynthesis takes place in green ____________ in iceans than green plants on land.
10. The name ____________ is given to the molecules created by the action of photosynthesis.
11. Scientists estimate that green plants on land create ____________ tons of carbohydrates each year.
12. The carbon dioxide that plants use to make carbohydrates comes from the ________________.
13. Carbon dioxide and water are low energy molecules. (T or F) ________
14. The word ____________________ means carbon united with water.
15. Simple sugars of single molecules are called ________________________.
16. Two ring-shaped sugar molecules can attach to each other, and a water molecule be removed. This process of joining is called ________________________________.
17. After two single sugar molecules are joined, they are called ________________.
18. When more than two simple sugar molecules join, they form a long chain-like molecule called a ____ ________________________________.
19. After harvesting the parts of mature plants to be made into alcohol fuel, these parts can be stored for long periods of time. (T or F) ________
20. The term processing means to break the complex molecules found in most plants into simple sugar molecules. (T or F) ________
21. Enzymes are chemicals that are used to help break the larger more complex molecules apart. (T or F) ________

22. Simple sugar molecule is the goal of processing. (T or F) ________

23. Yeast is composed of living organisms sometimes called ____________________.

24. Fungi (yeast) have the natural ability to digest simple sugar molecules to ____________________.

25. The digestive process of yeast on the simple sugar molecule is called ____________________.

26. Alcohol is the byproduct or waste from the fermentation process. (T or F) ________

27. The fermentation process by yeast on simple sugar forms carbon dioxide as a byproduct. (T or F) ________

28. ____________________ is required in the fermentation process.

29. ____________________ is the process of separating the water and alcohol after fermentation.

30. ____________________ is required in the distillation process.

31. Alcohol can be handled as a fuel similarly to gasoline. (T or F) ________

32. The burning of alcohol forms carbon dioxide and ____________________.

33. The burning of alcohol completes the renewable energy cycle. (T or F) ________

34. The products of burning can be used by growing plants in the renewable energy cycle. (T or F) ________

35. Alcohol has the same energy per gallon as gasoline. (T or F) ________

Answers

1. F (It is colorless.)
2. T
3. sun
4. Put together with light
5. T (This is called ionization.)
6. T (The amount of energy in a photon is called quantum.)
7. chlorophyll
8. T (The photons of sunlight can force electrons from their orbits around large molecules of chlorophyll of plants or from orbits of cesium in a photoelectric cell.)
9. algae
10. carbohydrate
11. 400 billion
12. atmosphere
13. T
14. carbohydrate
15. monosaccharides
16. dehydration
17. disaccharides
18. polysaccharide
19. T
20. T
21. T
22. T
23. fungi
24. alcohol
25. fermentation
26. T
27. T
28. energy
29. distillation
30. energy
31. T
32. water
33. T
34. T
35. F

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